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RESEARCH ARTICLE

Development of Solar-Wind-Hydro-Based Renewable Energy Teaching Kit (RETRI) as an Innovative Learning Media for Renewable Energy in Science Laboratories

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Abstract

This research aims to develop a solar-wind–hydro-based Renewable Energy Teaching Kit (RETRI) as an innovative learning medium in renewable energy education in science laboratories. The study uses research and development (R&D) methods that refer to the modified Borg & Gall model. The research stages include identification of potential and problems, data collection, product design, expert validation, trials, and revisions to produce a viable final product. The research data was collected through the validation of material experts and media experts, as well as through a limited trial to students of the Tadris Science study program. Data analysis was carried out qualitatively and quantitatively using the ideal percentage method. The novelty of this research lies in the proposal of RETRI as an integrative renewable energy learning kit, combining solar-wind-water power systems in one interactive practicum device that is digitally measured. Unlike previous learning media that were single and theoretical in nature, RETRI uniquely facilitates cross-understanding of energy sources through real-energy conversion simulations, simultaneous voltage-current measurements, and scientific module- based experimental guidance. This approach places RETRI as a model of a practicum tool that not only visualizes the concept of renewable energy but also connects the theory of physics with its application in the context of sustainability. The results of the study show that RETRI is considered very feasible with a percentage of validation of material experts of 97.5% and media experts above 95%. The results of the user test showed a significant improvement in students' conceptual understanding of renewable energy. This product is considered effective, safe, and easy to use for practicum activities in science laboratories. Thus, the developed RETRI significantly enhances students' conceptual understanding and serves as a practical model for sustainable energy education. The implications of this research open up opportunities for educational institutions to adopt renewable energy-based learning media that are applicable, environmentally friendly, and support the transition to green energy literacy in the future.

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INTRODUCTION

Energy is a fundamental element in social, economic, and technological development (Menna et al., 2022). However, the high dependence on fossil energy presents various problems such as a decline in energy reserves, greenhouse gas emissions, and the threat of a national energy crisis (Wang, 2024). Indonesia, despite its rich renewable energy potential, still faces a huge gap between the availability of clean energy and its utilization rate (Erdiwansyah et al., 2021). This energy problem demands systematic efforts to introduce renewable energy technology to the younger generation through educational channels.

On the other hand, the current challenges of science education lie in the low literacy of renewable energy, limited teaching aids, and learning that is still dominated by theoretical approaches (Santillán & Cedano, 2023). In many science laboratories, including the universities where this research was conducted, practicums related to solar, wind, and water energy are not adequately available. The absence of practicum media makes it difficult for students to understand the concept of energy conversion and the working mechanism of renewable energy systems in an applicative manner (Shahroury et al., 2023). This creates a gap between the theory being taught and the physical phenomena that should be directly observable (Borish & Lewandowski, 2023).

To answer these two problems, the energy crisis and the challenge of science education, learning solutions are needed that can bridge theory and practice, as well as integrate renewable energy technology in laboratory activities. Concrete-media-based learning that allows students to observe, measure, and analyze the energy conversion process is crucial in preparing sustainable energy literate human resources.

Research Issues

Observing these conditions, this study positions the main questions as follows (1) How to design a renewable energy practicum tool that is integrative, applicative, and according to the needs of science learning? (2) What is the level of feasibility and validity of the tool when tested by experts and students in the context of science laboratories?

METHOD

This research uses a Research and Development (R&D) approach which aims to produce a product in the form of innovative learning media Renewable Energy Teaching Kit (RETRI) based on solar-wind-hydro and test its feasibility and effectiveness in science learning. The R&D method was chosen because it is in accordance with the research objective, which is to create educational products that are valid, practical, and effective to use in the learning process. The adapted development model refers to the steps of Borg & Gall (Prayitno & Elan, 2018), but modified by Sugiyono (2019) to suit the research conditions, resources, and available time. In general, the development stages are carried out in seven main steps: (1) identification of potentials and problems, (2) information gathering, (3) product design, (4) expert validation, (5) product trials, (6) product revisions, and (7) product refinement (Fildaniyah & Abbas, 2023).

Subjek dan Sampel Penelitian

The subject of the study is a student of the Tadris Science Study Program, UIN Datokarama Palu. The trial sample consisted of: (1) Expert Judgment: two renewable energy material experts and two learning media experts; (2) Limited trial: 10 students of the class of 2024; (3) Field test: involving 22 students of the class of 2024.

Product Development

RETRI products are designed to be simple, economical, easy to use, and relevant to the learning needs of Tadris Science students. Each RETRI unit consists of:

- Mini solar panels, to convert light energy into electrical energy.
- DC generators, wind turbines and waterwheels, to demonstrate the conversion of mechanical energy into electrical energy.
- Digital voltmeter and amperemeter, to measure the voltage and electric current generated.
- Battery and LED output, to show the energy conversion results.
- Practicum guide module, which contains brief theories, experimental procedures, and student worksheets.

This media is expected to help students understand the relationship between renewable energy theory and its real-life applications (Aboagye et al., 2021). In addition, RETRI also supports project-based learning, as students can conduct hands-on experiments to measure electrical power from different energy sources.

Development Procedure

The RETRI development process is carried out through several systematic stages as follows:

a. Preliminary Study and Needs Analysis

The first step is to identify problems in the field through interviews with lecturers in the Basic Concepts of Science course and direct observation of practicum activities (Arini & Darmayanti, 2022). The results of the interviews show that renewable energy materials cannot be practiced due to the limitations of tools. This needs analysis is the basis for designing RETRI products to suit the curriculum and learning competencies of students.

b. Initial Product Planning

This stage includes the creation of a conceptual design of RETRI. The design includes the physical shape of the tool, component specifications, as well as the design of a simple electrical circuit that integrates the solar-wind-hydro system. The design is made using materials that are easy to obtain and environmentally friendly, such as wood, mini solar panels, propellers, small DC generators, and digital indicators. The purpose of the design is to produce an initial prototype that can be tested for function (Zivanovic et al., 2020).

c. Instrument Validity

Before being tested on students, the product that has been designed is validated by four experts consisting of two lecturers who are experts in the material (renewable energy and physics) and two experts in learning media (Putri, 2024). Instrument validity refers to the extent to which the instrument measures what it is supposed to measure. In this study, the validity of the instrument was tested through:

- Content Validity

  The validity of the content was carried out by two subject matter experts and two media experts who assessed the suitability of the instrument items with renewable energy learning competencies, the working principles of the RETRI tool, and the purpose of the practicum. The validator gives an assessment on the: (1) the suitability of the renewable energy concept, (2) the accuracy of the material in the RETRI module, (3) the clarity of the indicators and practicum instructions, (4) the feasibility of the display and the safety of the tools. The assessment uses a Likert scale of 1–5 and is expressed as a percentage of eligibility. The instrument is declared valid if the eligibility percentage is in the range of ≥ 80% ("Eligible" or "Very Eligible" category) (Darmana et al., 2024).

- Construct Validity

  The construct aspect was evaluated through the suitability of the instrument indicators to the theory of learning media development, renewable energy theory, and the characteristics of science practicum tools. The validator assesses whether each item of the questionnaire and observation indicators represents the construct to be measured, such as: (1) usability of the tool, (2) clarity of display, (3) accuracy of voltage-current measurement, (4) ease of use.

  The compatibility between the theory and the item of the instrument ensures that the instrument has good construct validity (Tavakol & Wetzel, 2020).

- Reliability

  Reliability indicates that the instrument is capable of delivering consistent results when used repeatedly under similar conditions (Ahmed & Ishtiaq, 2021). In this study, Instrument Reliability in RETRI Components was tested by the following procedures (1) Digital voltmeter & amperemeter calibration, (2) Repeated measurements, (3) Stability test

d. Product Revision

Input from validators is used as a basis for revising RETRI products. The revision includes improvements to technical aspects such as component layout, power cable safety, and completeness of the tool usage guide. Revisions are carried out until the product is considered suitable for use for the trial stage.

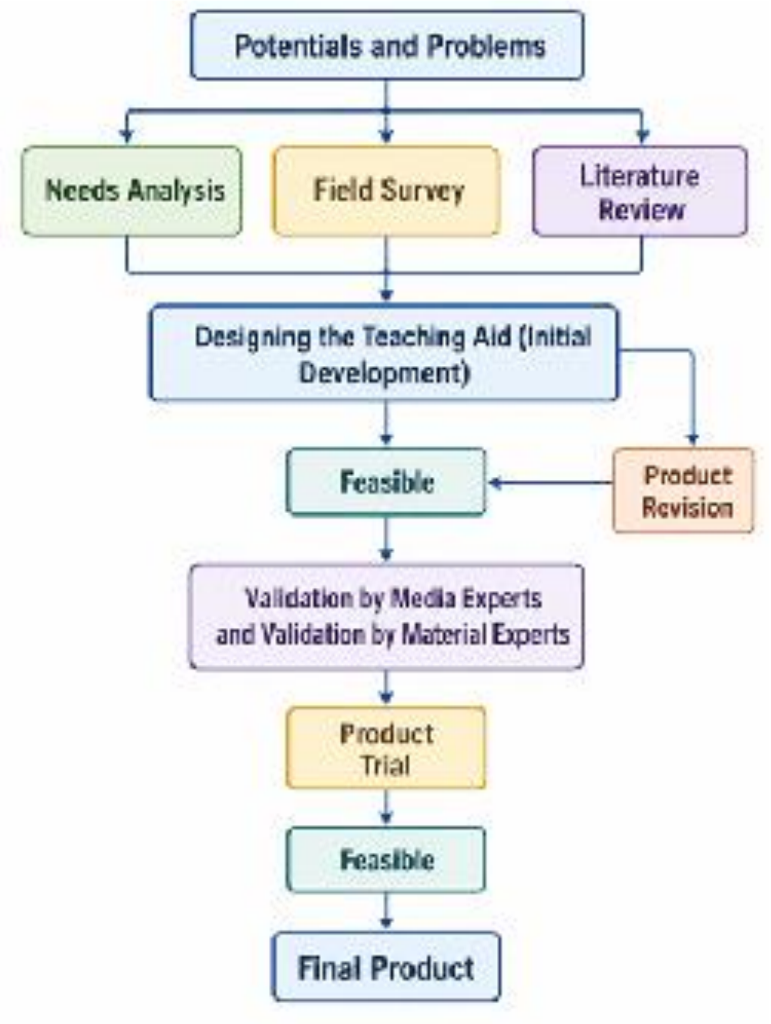


Figure 1. Development Procedure Flowchart

e. Product Trials

The trial was carried out for students of the Tadris Science study program class of 2024 who are taking the Basic Science Concept course. The trial aims to assess user response to the tool, the effectiveness of the media in helping to understand the concept of renewable energy, and the ease of use of the tool (García-Arévalo et al., 2022). The trial process is carried out in the science laboratory in the form of structured practicum activities. Students observe the results of voltage and current measurements from three different energy sources, then analyze the efficiency of the system using the worksheets provided.

f. Trial Data Analysis

The results of the trial were analyzed using two approaches. The qualitative approach was used to analyze the responses of students and lecturers to the ease of use and benefits of the tool, while the quantitative approach was used to calculate the feasibility score based on a questionnaire with the ideal percentage method (Vinita Singh, 2022). The product is declared "very feasible" if it obtains a score of ≥85%.

g. Final Products

After going through a revision and testing process, RETRI's final product was refined and declared feasible as an innovative learning medium for renewable energy. The final product is equipped with learning modules that explain the theory, work steps, and evaluation of practicum results, so that it can be used independently by lecturers and students in the laboratory (Churiyah et al., 2020).

Data Type

This study uses two types of data, namely qualitative data and quantitative data.

- Qualitative Data

  Qualitative data was obtained from the results of interviews, observations, and open responses from validators and students. This data provides an in-depth picture of user needs, advantages and disadvantages of tools, and the suitability of products for the learning context. Qualitative data analysis is carried out through data reduction, data presentation, and withdrawal Conclusions (Friedman et al., 2022).

- Quantitative Data

  Quantitative data were collected through questionnaires and validation results using a five-point Likert scale (Vagias, 2006). This data is used to assess the feasibility of RETRI based on aspects of material, media, and user response. In addition, data from student practicum measurements were also processed to assess the effectiveness of the tool in supporting the understanding of renewable energy concepts.

The assessment interpretation criteria were as follows: 81–100% (very feasible), 61–80% (feasible), 41–60% (moderately feasible), 21–40% (less feasible), and 0–20% (not feasible) (Tseng et al., 2016). Through a combination of qualitative and quantitative data, this research is expected to produce a valid, practical, and effective Renewable Energy Teaching Kit (RETRI) product as a learning medium. This product not only serves as a prop for the concept of renewable energy, but also as an educational medium that instills the value of sustainability, innovation, and awareness of the importance of the transition to clean energy for future generations (Bakar et al., 2022).

RESULT AND DISCUSSION

Expert Validation Results

1. Subject Matter Expert Validation

Validation was carried out by two subject matter experts. The assessment aspects include the suitability of the concept of renewable energy, the accuracy of working principles, the accuracy of measurement, and the relevance to learning competencies (Muliyati et al., 2023).

Table 1. Material Expert Validation Results

Aspects Assessed	Validator Score 1	Validator Score 2
Compatibility of renewable energy concepts	4	4
Precision of the working principle	4	4
Measurement accuracy	4	4
Integration of theory and practice	4	4
Relevance of learning	4	3
Total Score	20	19

Table 1 shows the five main aspects assessed: compatibility of renewable energy concepts, precision of the working principle, measurement accuracy, integration of theory and practice, and relevance of learning. Overall, the score given by validator 1 is 20, while validator 2 gives 19 out of a maximum score of 20. Both validators assessed that the concept of renewable energy in RETRI was appropriate and accurate in both theoretical and applicable aspects. A score of 4 on almost all indicators shows that fundamental concepts such as solar, wind, and hydro energy conversion have been designed in accordance with scientific principles.

A small difference appears in the relevance aspect of learning, where validator 2 gives a score of 3. This shows that there are recommendations to strengthen the linkage of modules with course learning outcomes. In general, the two validators agreed that RETRI has a good material structure, is accurate, and can be used to support renewable energy learning. The results of this validation confirm that RETRI is feasible to be applied as a renewable energy-based practical learning medium because it has met the academic content feasibility standards.

2. Media Expert Validation

Media experts assess the visual design aspects, ergonomics, and technical feasibility of the tool. Table 2 are five main assessment components, namely: tool design, ease of use, clarity of information, arrangement of components, and label quality. The validation results showed an average score of 4.8 out of 5, with a 96% eligibility percentage, which falls into the Very Eligible category. The design aspects of the tool, clarity of information, arrangement of components, and quality of labels all obtained a maximum score (5), indicating that RETRI was rated as having an excellent, aesthetic, and informative physical design. Components such as solar panels, wind generators, water turbines, voltmeters, and amperemeters are arranged proportionally, neatly, and easily identified by the user.

Meanwhile, the ease of use obtained a score of 4, which indicates that the media is easy to use, but there are still minor aspects that need improvement. The validator gave several suggestions, including: (1) arranging the voltmeter and amperemeter to be more precise and easier to read, and (2) improving the quality of the tool's label using waterproof materials to make it more durable and not easily damaged. Overall, the results of the media validation confirm that RETRI has met the criteria for good learning media, including aspects: visual, ergonomic, and technical functionality, so that it can be applied effectively in renewable energy practicum activities.

Table 2. Media Expert Validation Results

Assessment Components	Score
Tool design	5
Ease of use	4
Information clarity	5
Component layout	5
Label quality	5
Average score	4,8
Percentage of suitability	96% (Very Worthy)

Product Test Results (Solar-Wind-Hydro)

1. Solar Cell Product Testing

Measurements were made using a digital voltmeter and amperemeter with a simulation of direct sunlight. The results show that solar panels are able to generate stable voltage and current according to the theory of conversion of light energy to electricity (Figure 2).

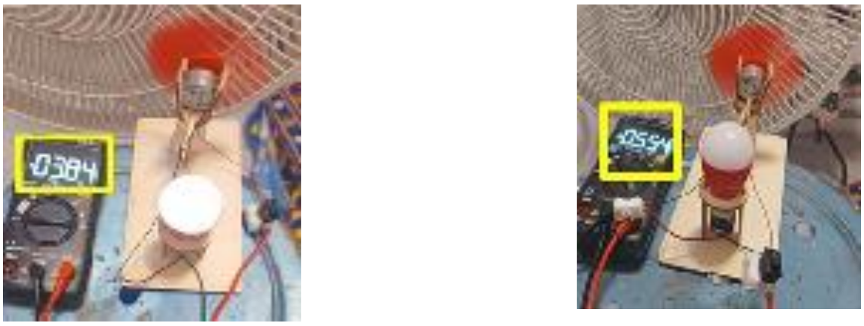
(a)

(b)

Figure 1. (a) voltage values (b) Current values on Solar cell Products

2. Wind Product Testing

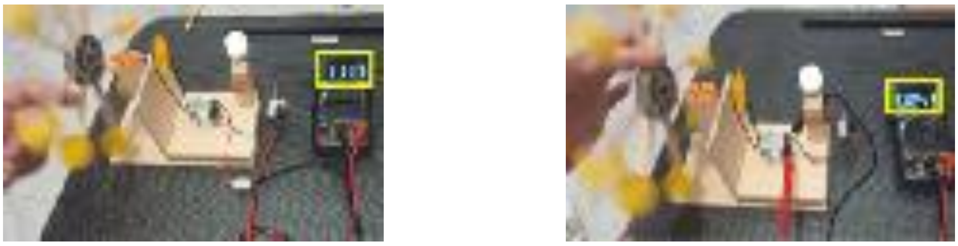
The test is carried out by directing artificial wind from the fan to the turbine blade (Figure 3)



(a) (b)
Figure 3. (a) Voltage value (b) current value on the wind product

3. Hydro Product Testing

The water flow is directed to the mini waterwheel to rotate the DC generator (Figure 4).



(a) (b)
Figure 3. (a) Voltage value (b) current value on Hydro Products

Field Test

The field test is carried out in two stages: (1) Initial trial (students who have taken courses). (2) Limited field tests (students who have not taken courses).

1. Initial Trial

Students stated that the tool was easy to use, the measuring tool was clearly readable, and the results of the experiment were according to theory (Table 3)

Table 3. Initial Test Results

Indicator	Value
Average Score	1,86
Eligibility Percentage	95,71%
Category	**Highly Worth It**

2. Limited Field Test

Limited field tests show significant improvement as students find these tools help to understand energy concepts more easily and realistically (Table 4)

Table 4. Limited Field Test Results

Test Stage	Percentage	Category
Limited Field Test	98,93%	Highly Worth It

Discussion

The results of the study show that the development of the Solar-Wind-Hydro-based Renewable Energy Teaching Kit (RETRI) has succeeded in achieving the main goal, which is to produce innovative learning media that is feasible, functional, and effective for use in renewable energy practicum. The data shows that RETRI has a very high level of feasibility based on expert assessments and field tests.

The validation of the material experts showed a feasibility percentage of 97.50%, which confirms that the content of RETRI is in accordance with the basic concept of renewable energy, is theoretically accurate, and is relevant for science learning. The subject matter expert also emphasized the importance of improving the safety aspect of solar panel connections, wind turbines, and water turbines, which have then been improved by researchers to make them safer and easier to use by students.

Media expert validation corroborates these results with a 96% feasibility percentage, indicating that the tool design, component layout, and display clarity are considered excellent. Suggestions for improvements from validators, such as the arrangement of voltmeter-amperemeters and the use of waterproof labels, have also been implemented to improve the visual quality and durability of the tool.

At the field test stage, RETRI again showed excellent performance. The initial trial given to students who had followed the Basic Concept of Science produced a feasibility percentage of 95.71%, which included aspects of ease of operation, clarity of reading of measuring instruments, and suitability of experimental results with energy conversion theory. Meanwhile, the field test was limited to students who had not received the material showed an increase in feasibility to 98.93%, indicating that this tool was able to bridge students' initial understanding of renewable energy effectively.

These results are in line with the findings of Sanjaya et al. who developed renewable energy teaching aids for high school students and reported an increase in concept understanding as well as student creativity in practicum activities (Sanjaya et al., 2019). Similarly, Mukhlis and Rendi found that the solar-powered mini house they developed was effective as a learning medium as well as a vehicle for exploring the energy efficiency of solar panels (Ali & Efendi, 2022).

However, compared to these studies, RETRI offers a higher degree of integration and complexity of concepts. Previous products generally only focused on one type of energy source, for example only solar energy. In this study, RETRI explicitly combines three solar-wind-hydro energy sources in one coherent kit, equipped with real-time measurements of voltage and current via digital indicators. This integrative approach favors cross-concept learning (energy conversion, efficiency, and energy source comparison), which in turn contributes to improving students' conceptual understanding at the college level.

The findings of this study are also in line with the report of Ega M.D. et al. who used the ADDIE model to develop renewable energy media at the junior high school level and obtain a high validity index (Muhammad et al., 2023). As in the study, RETRI shows that the development process based on a systematic R&D model (needs analysis-design-validation-revision-trial) results in a product that is pedagogically robust and technically functional. However, the new contribution of this research lies in the context of users (Tadris Science students), the integration of three energy sources, and the explicit alignment with the principles of Education for Sustainable Development (ESD). Thus, RETRI not only serves as a teaching tool, but also as a means of internalizing the value of energy sustainability in the higher education curriculum.

More broadly, the results of this study are also consistent with the findings of other studies that report that contextual learning kits can improve students' energy literacy and environmental awareness; "These results are in line with research showing that contextual kits improve energy literacy among students." (Utari et al., 2023). However, RETRI goes beyond the basic literacy function by providing experimental scenarios that allow students to quantitatively measure, compare, and analyze efficiency. This strengthens RETRI's position as a model teaching kit that not only shows phenomena, but also trains scientific skills such as designing experiments, analyzing data, and drawing evidence- based conclusions.

Although it is very feasible, RETRI has some technical limitations. For example, the resolution of a digital measuring instrument is limited to 0.01 V/A so it is very small to be less sensitive for energy measurement. In addition, the performance of mini wind turbines is still affected by artificial wind conditions so that the measurement results are not always stable in closed spaces.

Technical Limitations of Measuring Instruments

One of the main limitations of RETRI lies in the resolution of digital measuring instruments (voltmeters and amperemeters) which reaches only 0.01 V/A. Although sufficient for ground-level demonstrations, these resolutions: (1) are less sensitive to detect small variations in voltage and current generated by miniature energy systems, (2) make value changes at low light intensity, slow wind speeds, or small water discharge becomes less visible, (3) potentially resulting in readings that do not fully represent real fluctuations in small-scale renewable energy. In other words, it is better suited for macro measurements in practicums, but less optimal for tests that demand high precision.

Performance Instability of Mini Wind Turbines

The next limitation relates to the artificial wind source used in the testing of the prototype of the mini wind turbine. In an enclosed room environment: (1) the wind speed of the fan is inconsistent, (2) the direction of the airflow changes according to the resistance of the space, (3) small turbulence may affect the rotation of the rotor.

As a result, the resulting voltage and current become unstable, and readings on the measuring instrument can fluctuate significantly. This shows that the performance of wind energy systems is highly dependent on environmental conditions and does not fully reflect natural conditions in the field.

Potential Measurement and Interpretation Bias

Some forms of potential bias are also worth noting: (1) Environmental Bias: Testing is conducted in laboratory space conditions, not natural conditions. (2) Bias Operator: Assembly and measurement are carried out by researchers and students. (3) Instrument Bias: Because measuring instruments have limited accuracy, each reading can contain built-in errors.

Limitations of Product Generalization

RETRI is designed in the form of an educational-scale miniature, not as a representation of an industrial-scale renewable energy system. Therefore: (1) the efficiency of solar-hydro energy cannot be equated with commercial technology, (2) the results of the practicum only illustrate basic principles, not advanced technical calculations.

Implications of Limitations on Use

These limitations do not reduce the feasibility of RETRI as a learning tool. It needs to be understood so that: (1) the user does not interpret the results as absolute technical values,

(2) the interpretation of the practicum is carried out in the pedagogical realm, (3) the next stage of development can improve technical aspects such as the precision of the measuring instrument, the stability of the rotor.

Overall, RETRI has proven to be a learning medium that supports the improvement of renewable energy literacy, provides an authentic practicum experience, and is able to overcome the lack of laboratory facilities related to clean energy. This product is effective for integrating theory and practice directly, making it suitable for use and further development in science learning.

CONCLUSION

Solar-wind-hydro energy-based RETRI has been successfully developed and demonstrated a very high level of feasibility through expert validation and student trials, thus confirming its effectiveness as a comprehensive renewable energy learning kit. Interactive design with real-time digital measurements not only improves the understanding of energy conversion concepts, but also strengthens scientific skills, sustainability awareness, and a more authentic practicum experience. Further research needs to evaluate the long-term impact on energy literacy, integrate more precise sensor technology, improve turbine stability, and test the scalability of RETRI to be implemented in various educational institutions in the context of sustainable energy learning.

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